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RESEARCH MEMORANDUM

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... INVESTIGATION OF THE R-2800-21 EN...

IN THE P-47G AIRPLANE

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... CYLINDER TEMPERATURE DISTRIBUTION

...d J. Pesman and Samuel J. Kaufman

...aft Engine Research Laboratory
Cleveland, Ohio

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

for the

Air Materiel Command, Army Air Forces

ALTITUDE COOLING INVESTIGATION OF THE R-2800-21 ENGINE IN THE P-47G AIRPLANE

II - INVESTIGATION OF THE ENGINE AND AIRPLANE VARIABLES AFFECTING THE CYLINDER TEMPERATURE DISTRIBUTION

By Gerard J. Pesman and Samuel J. Kaufman

SUMMARY

The data obtained from cooling tests of an R-2800-21 engine installed in a P-47G airplane were studied to determine which engine and airplane operation variables were mainly responsible for the extremely uneven temperature distribution among the 18 engine cylinders obtained at the medium and high engine-power conditions. The tests consisted of flights at altitudes from 5000 to 35,000 feet for the normal range of engine and airplane operation.

The effects of the individual variables were determined by selecting data in which all but one variable were held reasonably constant and then plotting these data to determine the change in the temperature distribution with change in the variable under investigation.

The results of the study showed that a flow condition in the induction system associated with the wide-open throttle position, which affected either the fuel air or charge distribution, was primarily responsible for the uneven temperature distribution. For the range of fuel-air ratios tested (0.080 to 0.102), the temperature distribution remained essentially unchanged. The individual effects of thrust-axis inclination, cowl-flap opening, and quantity of auxiliary air were found to be secondary in importance. At low angles of throttle opening, engine speed was found to have little effect on the temperature pattern.

INTRODUCTION

At the request of the Air Materiel Command, Army Air Forces, an investigation was conducted at the NACA Cleveland laboratory to obtain information on the cooling characteristics of the R-2800 engine. As a part of this investigation, flight tests were conducted on an R-2800-21 engine installed in a P-47G airplane for variable engine and airplane operating conditions at altitudes ranging from 5000 to 35,000 feet (reference 1). An analysis of the cooling data obtained was made to determine the effect of altitude cooling-air conditions on the engine-cooling characteristics and is also presented in reference 1. The cylinder-temperature values considered were the average of the 18 cylinder temperatures.

The results of these flight tests showed that an extremely nonuniform and varying cylinder temperature distribution with engine and airplane operating conditions existed from cylinder to cylinder. Inasmuch as the performance of an air-cooled aircraft engine is severely limited when the individual engine cylinders operate at widely different temperatures because of increased cooling air and increased fuel consumption necessary to cool the hottest cylinder, a study was made of the temperature distribution of the individual cylinders as affected by the various engine and airplane operating variables. The determination of the effect of the engine and airplane operating variables on the temperature distribution was made by selecting different series of flights in which all of the variables except one were essentially constant and by so plotting the cylinder temperatures as to indicate the separate effect of each variable. The factors studied were: throttle setting, charge-air flow, engine speed, quantity of auxiliary air, fuel-air ratio, thrust-axis inclination, and cowl-flap opening.

POWER-PLANT INSTALLATION

The R-2800-21 engine is an 18-cylinder, double-row radial, air-cooled engine with a normal rating of 1625 brake horsepower at an engine speed of 2550 rpm and a take-off rating of 2000 brake horsepower at 2700 rpm. The supercharger equipment consists of a single-stage, single-speed, gear-driven blower (gear ratio, 7.6:1; impeller diameter, 11 in.) and a General Electric type C-1 turbosupercharger. A Bendix-Stromberg PT-13G1 injection-type carburetor, which meters fuel to the inlet of the engine-stage blower, was used. The engine is equipped with a four-bladed Curtiss Electric controllable-pitch propeller (blade drawing No. 714-1C2-12), which has a diameter of

12 feet, 2 inches, and is fitted with shank cuffs. The propeller-reduction-gear case was replaced by a Pratt & Whitney torquemeter having a reduction gear ratio of 2:1.

The engine cowling is fitted with eight adjustable cowl flaps, which extend around the upper half of the cowling. Additional fixed cooling-air openings are provided around the lower half of the cowling down to the auxiliary air duct. The opening of the auxiliary air duct, which provides air for the carburetor, the intercooler, the oil cooler, and the exhaust-duct cooling is located inside the engine cowling near the bottom of the engine. Figure 1 shows the general arrangement of the cowling, the cooling-air system, and the auxiliary air ducting.

INSTRUMENTATION

Only the equipment that specifically pertains to the measurement of the variables of particular importance to the present study is completely described. Other phases of the instrumentation are described in detail in reference 1.

Temperature-Measuring System

Unless otherwise noted, all temperatures were determined by means of iron-constantan thermocouples and four NACA recording galvanometers. A diagrammatic sketch of a typical complete thermocouple circuit is shown in figure 2. The thermocouple lead wires were joined to copper wires, which were in turn connected to the recording galvanometers through motor-driven selector switches. The junctions between the thermocouples and the copper wires were made at multiple bar connectors, which were placed in insulated boxes and were used as the cold junctions of the thermocouple circuits; the cold-junction temperatures were measured by resistance thermometers placed in the insulated boxes. A calibration point was obtained for each galvanometer during each test run by taking galvanometer readings of a known standard voltage; the effect of changing galvanometer calibration was thus eliminated. The recording time for the 200 temperatures obtained during each flight run was approximately 3 minutes. The temperature-measuring system was considered to have an accuracy of $\pm 7^{\circ}$ F.

The cylinder-wall temperatures were measured by thermocouples located on the head and barrel of each of the 18 cylinders. The location and designation of these cylinder-wall thermocouples (fig. 3) are as follows:

(1) At rear spark plug with standard gasket-type thermocouple T_{12}

(2) In rear spark-plug boss with thermocouple T_{35} embedded to depth of one-sixteenth inch

(3) In rear middle of the head circumferential finning with thermocouple T_{19} embedded about one-sixteenth inch into outer cylinder-wall surface

(4) In rear of barrel two-thirds of way up with thermocouple T_6 embedded about one-sixteenth inch into aluminum-barrel muff

(5) At rear of cylinder-base flange with thermocouple T_{14} spot-welded to flange

General Instrumentation

Airspeed, engine speed, turbosupercharger speed, mixture setting, throttle setting, oil-cooler flap setting, intercooler shutter setting, free-stream impact pressure, free-stream static pressure, and thrust-axis inclination were all recorded by standard NACA flight recorders. Position indicators were connected to the cowl flaps, turbosupercharger waste gate, and intercooler shutter, the readings of which were recorded during flight. Because all runs were made in level flight, it was assumed that the inclinometer reading directly gave the angle between the thrust axis and the relative wind. The free-stream impact pressure was measured by a shielded total-pressure tube installed on a boom on the right wing. The boom also carried a standard NACA swiveling static tube for measuring the free-stream static pressure. The free-air temperature was measured by a flight-calibrated resistance thermometer installed under the right wing.

The torque pressure indicated by the torquemeter, which was installed in place of the conventional nose section to determine the engine power, was read on a gage in the cockpit and recorded by the pilot.

The charge-air flow was measured by two calibrated venturi meters placed in the two parallel charge-air ducts between the intercooler and the carburetor, as shown in figure 1. A flow-bench calibration of the carburetor in which the fuel flow was related to the carburetor compensated-metering pressure furnished the method of measuring the fuel flow in the tests. A verification of the flow-bench tests was obtained by a calibration of the carburetor in an altitude air box made by measuring both the compensated and uncompensated metering pressures over the normal range of air and fuel flow obtained in flight.

FLIGHT PROGRAM AND TEST PROCEDURE

The general flight program from which the data were taken was divided into three general phases:

(1) Variable cooling-air pressure drop with constant engine power and speed

(2) Variable engine power with constant cooling-air pressure drop and engine speed

(3) Variable engine speed with constant cooling-air pressure drop and engine power

In setting the test conditions, the engine power was controlled by the throttle and the turbosupercharger, the engine speed by the propeller governor, and the cooling-air pressure drop by the cowl flaps and the airplane velocity. The velocity was changed at constant power by extending the landing gear.

Flights were made at altitudes from 5000 to 35,000 feet over as wide a range of power and cooling-air pressure drop as level-flight conditions would permit. In most flights the fuel-air ratio was permitted to vary in the manner determined by the carburetor automatic-rich setting. For the flight in which fuel-air ratio was the main variable, the mixture strength was changed by manually controlled bleeding of the carburetor-metering pressure chamber.

METHOD OF ANALYSIS

The effect of a variable on the engine temperature distribution was determined as follows: An average of the 18 rear-spark-plug-gasket temperature readings (T_{12} in fig. 3) was obtained for each run. The difference between this average temperature and the individual cylinder temperatures was plotted on a polar diagram; a temperature-difference pattern for each run was thus obtained. Patterns for runs to be compared in the determination of the effect of a particular variable were plotted on the same diagram and changes in the shape or the position of the patterns from run to run gave an indication of the changes in temperature distribution due to a change in the variable.

Although thermocouple T_{12} was used throughout the analysis, thermocouples T_{19} or T_{35} responded in a similar manner to changes in operating variables and could also have been used. In order to make these data comparable with other tests based on thermocouple indications having the same general location as T_{19} or T_{35}, relations between the various thermocouple temperatures are shown in figures 4 to 7. A sufficient number of barrel-temperature patterns (T_6 in fig. 3) were also plotted and analyzed to determine whether the trends in barrel temperature closely followed those shown by the rear-spark-plug-gasket thermocouple.

RESULTS AND DISCUSSION

The results of the investigation are graphically shown in figures 8 to 19. The discussion refers only to the R-2800-21 engine as installed in the P-47G airplane for the range of conditions shown by the table in each figure. The table also lists the average engine temperature for each run. All runs were made with the oil-cooler flap open and with the mixture control set in the automatic-rich position unless otherwise specified. The omission of any point on the patterns denotes a thermocouple failure.

Reproducibility of data. - The reproducibility of the data is shown by figure 8. One run selected was made near the beginning of the test program, the other near the end. The temperatures of all of the cylinders except cylinder 10 fall within the precision limits ($\pm 7^\circ$ F). It was therefore considered that the temperatures would reproduce themselves under similar conditions and that the data were dependable.

Characteristic temperature distribution. - Temperature-difference patterns (figs. 9 and 10) were plotted in composite form for a large number of runs representing a normal range of operating conditions in order to obtain an over-all picture of cylinder-head-temperature and cylinder-barrel-temperature distribution for the engine. The maximum and minimum points obtained for all the runs considered are connected by solid lines and the intervening area is shaded to represent the range over which the individual cylinder temperatures could be expected to deviate from the average. The dashed-line patterns indicate the temperature deviations of three runs at the typical operating conditions listed in each table.

The first distribution diagram (fig. 9) shows that the rear-spark-plug-gasket temperature T_{12} may vary from 65° F below engine average (cylinder 16) to 125° F above average (cylinder 10). A study of additional maximum temperature data in conjunction with figure 9 shows that above 1100 horsepower cylinder 10 is predominantly the hottest cylinder and cylinder 4 the next hottest. Below 1600 horsepower cylinder 4 is occasionally the hottest and below 1100 horsepower any one of several front row (even number) cylinders may have the highest temperature.

The temperature-deviation pattern for the run indicated on figures 9 and 10 by symbol □ is typical of high-power conditions. The pattern is characterized by high temperatures at cylinders 4 and 10, a sudden drop to subaverage temperatures for cylinders 5 and 11, and generally subaverage temperatures around the engine from cylinder 11 to 3. The actual rear-spark-plug-gasket temperature spread for this run was approximately 150° F with cylinder 10 operating 105° F above average (fig. 9). The low-power pattern (symbol ◇), on the other hand, has no prominent deviations from average, although it is somewhat ragged. The maximum deviations for this run are 30° F (cylinder 8) and -40° F (cylinder 3).

The distribution diagram of the cylinder-barrel temperature deviation (fig. 10) shows that the barrel temperatures T_6 do not vary as widely as the rear-spark-plug-gasket temperatures T_{12}. The maximum below-average temperature was 30° F (cylinder 7) and the maximum above-average temperature 60° F (cylinder 10). Except for small variations, the temperature patterns of the cylinder heads and barrels are similar; therefore no additional barrel-temperature patterns are included.

Effect of Engine Variables

Throttle setting. - Changing the throttle setting from 28° to 78° (full open) but keeping the charge-air flow constant resulted in the large changes in the temperature patterns shown in figure 11.

The actual temperature spread was changed from 50° to 112° F. The temperature of cylinder 10 was changed from 25° to 80° F above engine average and cylinder 4 from 10° to 60° F above average. The temperature distribution was changed from one reasonably even to one with predominant peaks at cylinders 4 and 10. Throttle position is not, however, a primary variable and therefore the distortion of the temperature distribution is the result of a change in either fuel-air distribution or charge distribution caused by the change in throttle angle.

As a check on the result shown by figure 11, two additional groups of data were selected and plotted in figures 12 and 13. The data for figure 12 were so selected that the throttle positions were between 35° and 48° but the range of the other variables affecting the temperature distribution were disregarded. The data for figure 13 were selected in a like manner except that the throttle was maintained wide open for all runs. The limits of all variables are listed in the table accompanying each figure.

Comparison of figures 12 and 13 confirms the result indicated in figure 11. It is quite evident that the fuel or charge-air-flow characteristics of the induction system are adversely affected when the throttle is in the wide-open position. Inspection of figure 12 also shows that the beneficial effect of the turbulence created by the partly open throttle exists up to a throttle angle of at least 48°. Maintaining throttle angles at 48° or less could therefore be used as a simple means of achieving a relatively satisfactory temperature distribution for this engine-airplane configuration where power requirements do not demand the wide-open throttle position. Data between throttle angles of 48° and 78° (wide-open) were not available to indicate whether the beneficial effect of throttle turbulence might extend above the 48° throttle-angle position.

Charge-air flow. - When the charge-air mass flow was changed at a constant throttle angle, the temperature level of several cylinders was changed but the characteristic temperature distribution was not materially changed (fig. 14). A readjustment occurred with an increase in charge-air flow but there was no evidence of the typical high-power pattern (wherein cylinders 10 and 4 are predominantly hot) shown in figure 9. The temperatures of the lower cylinders (7 to 12) increased from 10° to 25° F more than the engine average temperature. The effect on the rest of the engine was erratic. The change does not indicate that the variation of charge-air flow is unimportant. When throttle turbulence is not present, it is probable that as the charge-air mass flow is increased, the temperature distribution progressively changes from that shown in figure 14 to that shown by the symbol □ in figure 9.

In order to vary the charge-air rate and still maintain the throttle angle constant, it was necessary to vary the engine speed. On the basis of figure 15, however, it was not considered that engine speed was responsible for all of the variation indicated by figure 14.

Engine speed. - Small random changes in the temperature pattern occurred when the charge-air flow was held constant and the engine speed was varied from 2200 to 2695 rpm (fig. 15). The maximum change, from 10° F below average to 15° F above average, occurred on cylinder 4 although this change was not progressive with changing engine speed. These patterns are for partly open throttle conditions, however, and the result might have been different for wide-open throttle, high-power conditions.

Quantity of auxiliary air. - As previously explained, the intercooler-cooling air, the oil-cooler air, the charge air, and the air for cooling the exhaust duct are all part of the main cooling-air stream and are diverted to the auxiliary air duct at the bottom of the engine cowling.

In order to determine whether changing the quantity of the auxiliary air by adjusting the intercooler shutter from closed to five-sixths open would change the cooling-air distribution and thus affect the temperature distribution, figure 16 was plotted. The figure shows that the effect was small even though at the five-sixths open position the intercooler air is estimated to constitute about one-fifth of the total air entering the cowling.

Fuel-air ratio. - The variable fuel-air-ratio data plotted in figure 17 indicate that the temperature distribution remained essentially unchanged with a change in engine fuel-air ratio. When the fuel-air ratio was varied from 0.080 to 0.102, the temperature of the hottest cylinder (cylinder 10 in this case) was increased only 13° F above the average. In this range of fuel-air ratios, however, the mean effective gas temperature will vary almost linearly with the fuel-air ratio and thus an increase in fuel-air ratio may be reflected by all the cylinders and no change in temperature distribution will be obtained.

Effect of Airplane Variables

Thrust-axis inclination. - Operational limitations of the P-47G airplane made it impossible to obtain variation of thrust-axis inclination without an accompanying variation of airplane velocity and thus of engine-cooling-air impact pressure. Because impact pressure should theoretically have little effect on the cooling-air distribution and thus on the engine temperature distribution, the combined effect of the two interrelated variables is assumed to represent principally the effect of thrust-axis inclination.

When the thrust-axis inclination was changed from 1.5° to 4.0° (impact pressure changed from 31.4 to 15.8 in. water) the temperature level of the upper left of the engine increased and that of the lower right decreased (fig. 18). The above-average temperature of cylinder 10 was decreased 8° F, whereas the above-average temperature of cylinder 4 was increased 30° F. This shift in temperature distribution is consistent with the shift in the cooling-air pressure-drop distribution (not presented) obtained with change in thrust-axis inclination. The relative magnitude of the change in the temperature distribution due to this variable is about the same as that due to most of the other variables and is not considered of primary importance.

Cowl-flap opening. - Figure 19 shows that opening the cowl flaps caused the upper cylinders (16 to 4) to run progressively cooler and the lower cylinders (8 to 13) to run progressively hotter with respect to the average engine temperature. This change in temperature distribution with cowl-flap position is a result of the location of the cowl flaps over the upper half of the cowling; hence, opening the cowl flaps favors the cooling-air flow over the upper cylinders.

General Discussion

The effect of throttle position indicates that the configuration of the induction system is primarily responsible for the unsatisfactory temperature distribution at high-power wide-open throttle conditions. This result, however, does not mean that the effects of other variables can be entirely discounted because there may be certain combinations of operational conditions in which the effect of variables normally not important might be additive and thus create large deviations in the temperature distribution.

SUMMARY OF RESULTS

The results of the study to determine what effect the engine and airplane variables have on the cylinder temperature distribution of the R-2800-21 engine as installed in a P-47G airplane apply only to this engine-airplane combination for a normal range of conditions. These results are summarized as follows:

1. A flow characteristic of the induction system associated with the wide-open throttle condition, which affected the fuel-air distribution or the charge distribution, was primarily responsible for the uneven cylinder temperature distribution of the R-2800-21 engine. The temperature spread among the 18 cylinders of the engine was increased from 50° to 112° F by a change in throttle position from 28° to 78° (wide-open throttle) at constant power.

2. For the range of fuel-air ratios tested (0.080 to 0.102), the temperature distribution remained essentially unchanged.

3. The thrust-axis inclination, the cowl-flap position, and the quantity of air taken from the bottom of the engine cowling by the carburetor, intercooler, and oil coolers were of secondary importance with respect to their individual effects on the cylinder temperature distribution.

4. The effect of engine speed on the temperature distribution was of secondary importance at partly open throttle conditions. Data to indicate the effect at high-power wide-open throttle conditions were not available.

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1. Manganiello, Eugene J., Valerino, Michael F., and Bell, E. Barton: Altitude Cooling Investigation of the Pratt & Whitney R-2800-21 Engine in the P-47 Airplane. I - High-Altitude Cooling Correlation. NACA MR No. E5J11, Army Air Forces, 1945.

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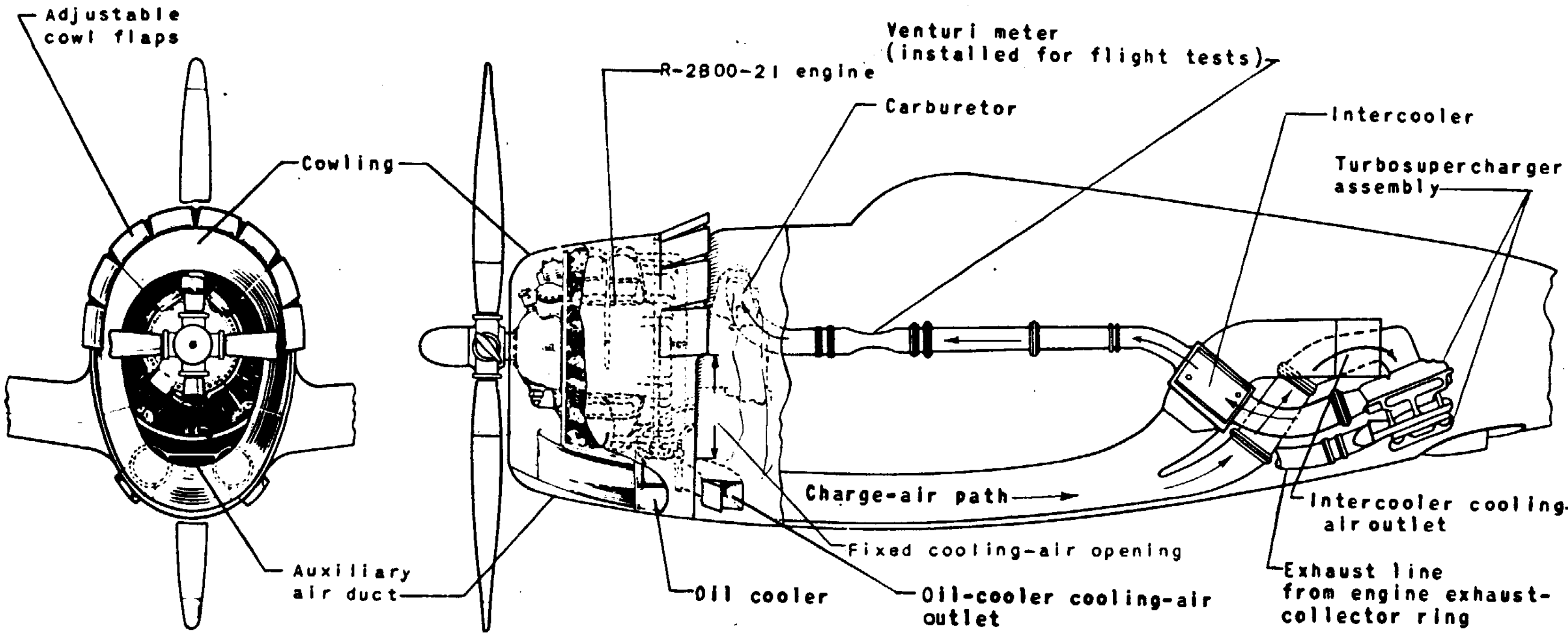

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Figure I. - Power-plant installation in P-47G airplane.

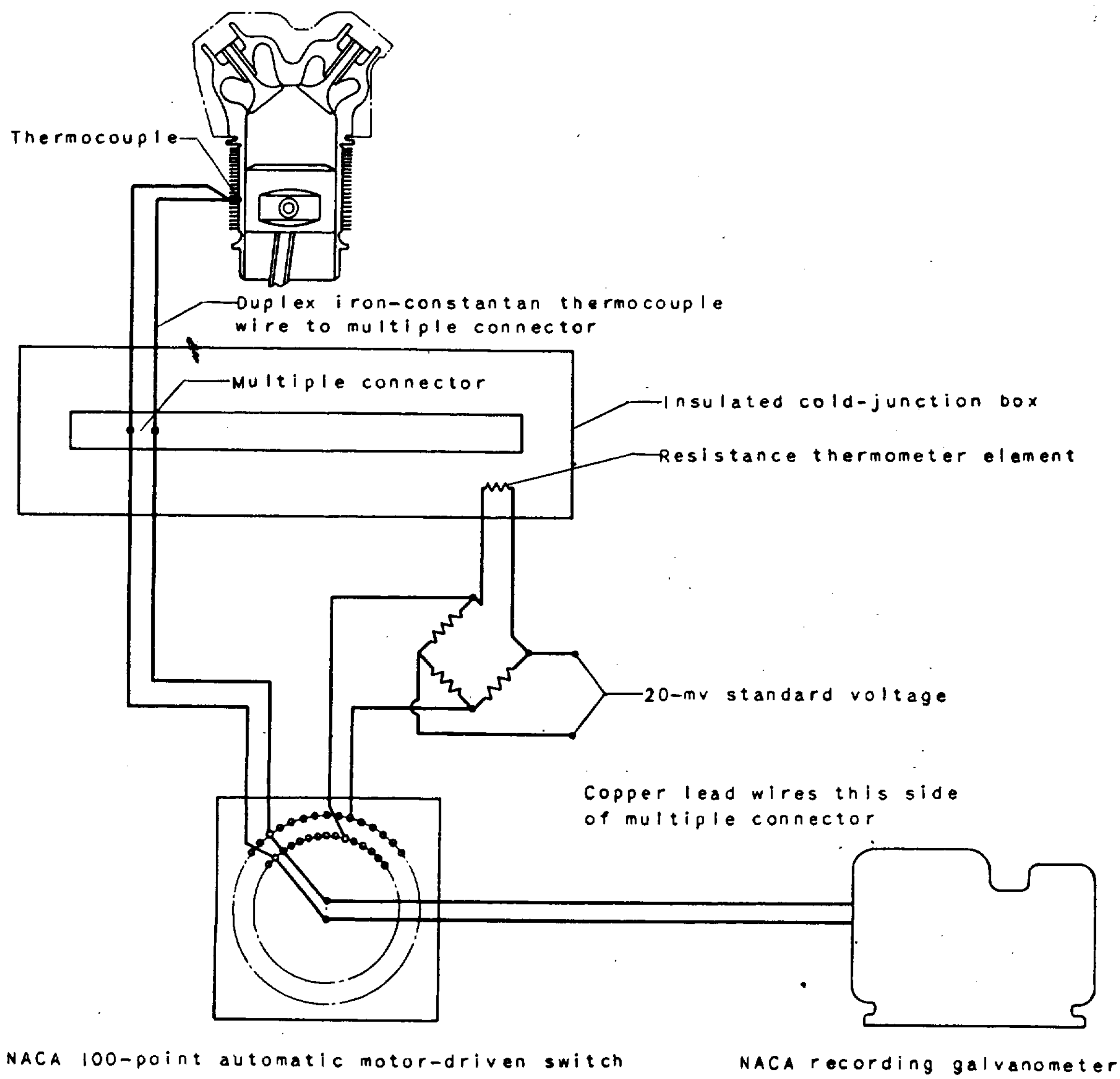

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Figure 2. - Diagrammatic sketch of thermocouple circuit for flight cooling tests of R-2800-21 engine in P-47G airplane.

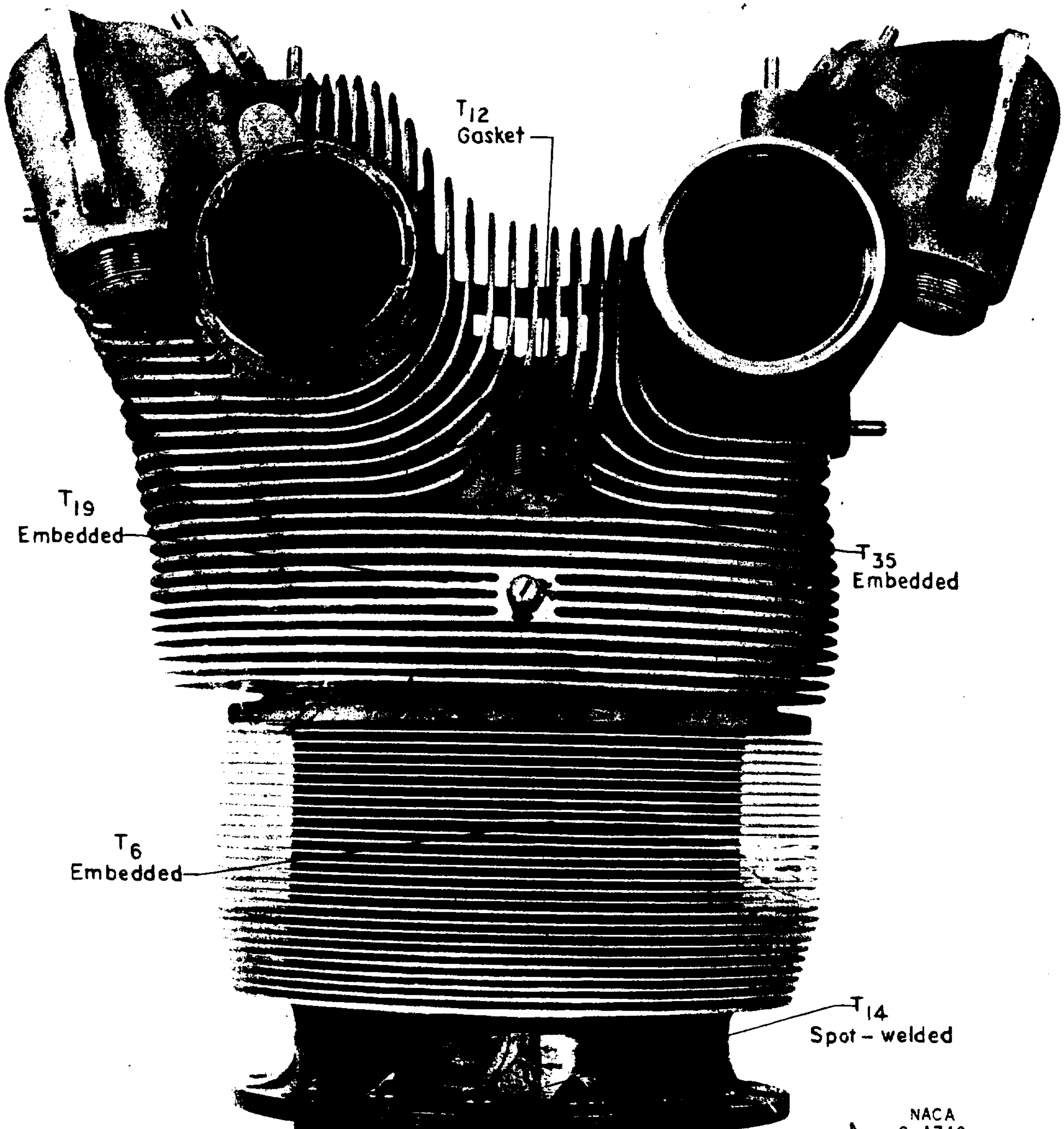

Figure 3. - Cylinder thermocouple locations.

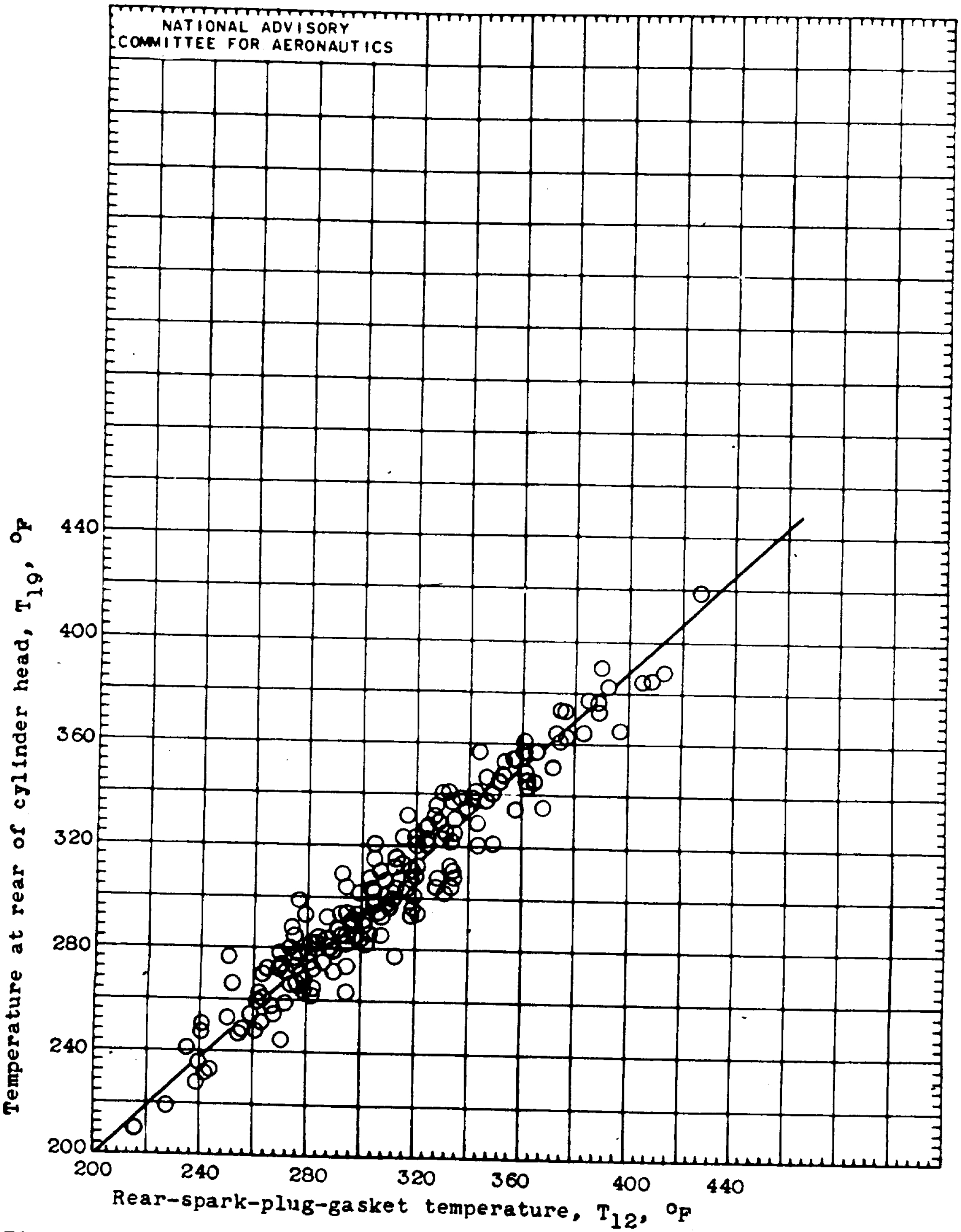

Figure 4. - Relation of individual cylinder-head temperature T_{19} to corresponding rear-spark-plug-gasket temperature T_{12}. Data from flight tests of R-2800-21 engine in P-47G airplane.

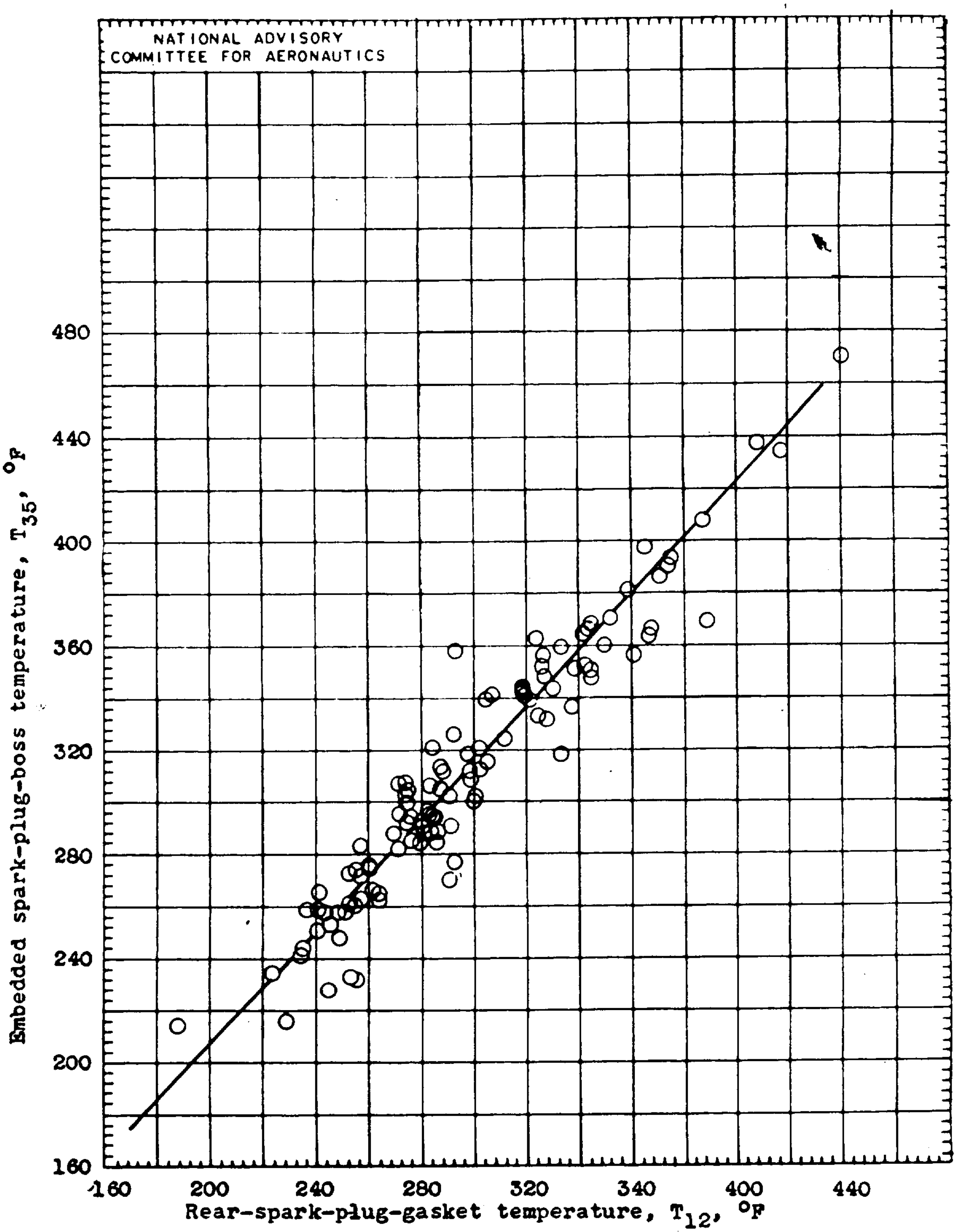

Figure 5. - Relation of individual embedded spark-plug-boss temperature T_{35} to corresponding rear-spark-plug-gasket temperature T_{12}. Data from cooling flight tests of R-2800-21 engine in P-47G airplane.

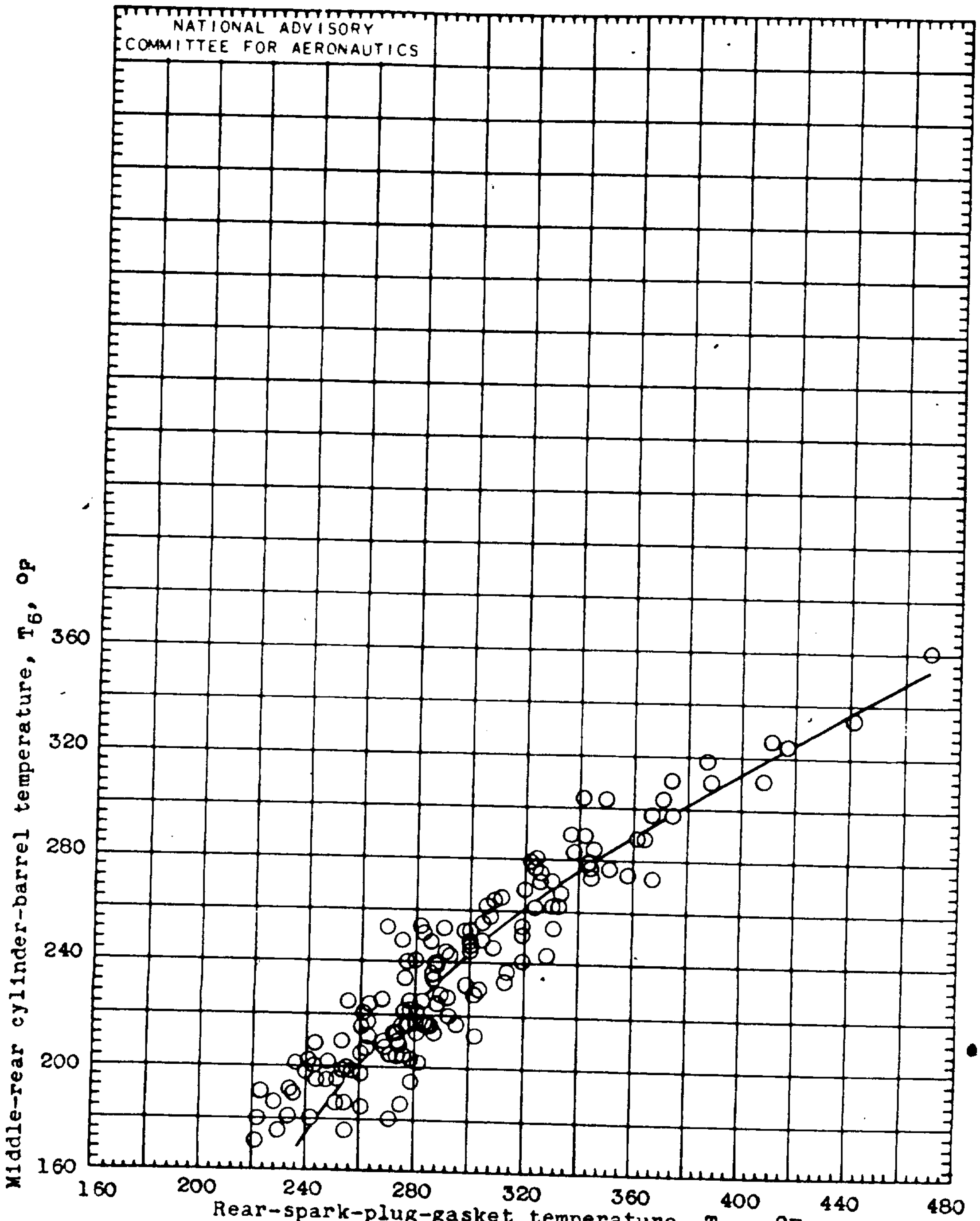

Figure 6. - Relation of temperature at rear of individual cylinder barrel T_6 to corresponding rear-spark-plug-gasket temperature T_{12}. Data from cooling flight tests of R-2800-21 engine in P-47G airplane.

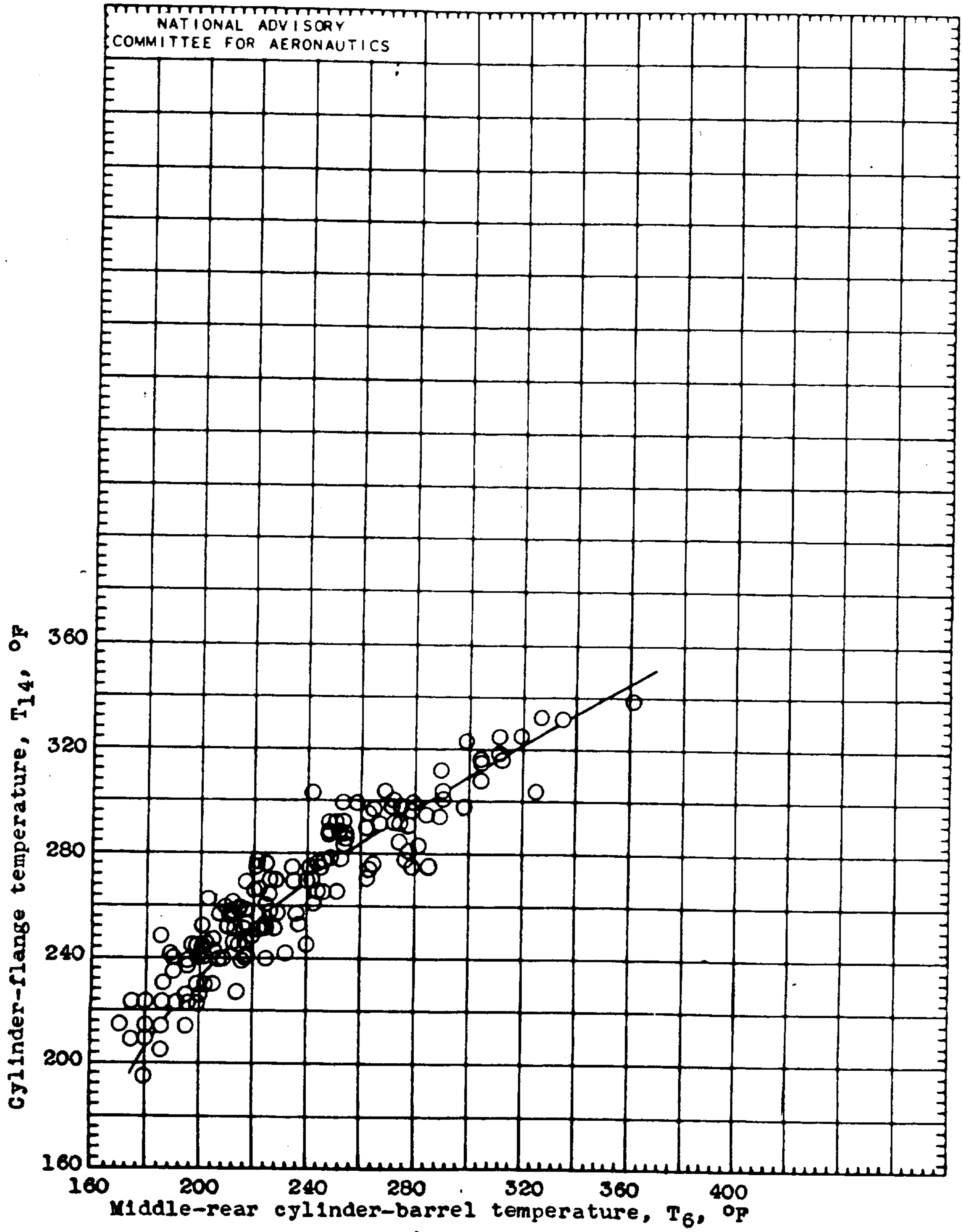

Figure 7. - Relation of individual cylinder-flange temperature T_{14} to corresponding rear cylinder-barrel temperature T_6. Data from cooling flight tests of R-2800-21 engine in P-47G airplane.

Symbols	Run	Free-stream impact pressure (in. water)	Density altitude (ft)	Free-air temperature (°F)	Cowl-flap opening (deg)	Intercooler-shutter opening (sq in.)	Inclination of thrust axis (deg)	Cooling-air pressure drop (in. water)	Manifold pressure (in. Hg absolute)	Charge-air flow (lb/sec)	Engine speed (rpm)	Brake horsepower	Carburetor-air temperature (°F)	Average T_{12} engine temperature (°F)	Engine fuel-air ratio	Throttle opening (deg)
○	19-3	43.2	5500	44	[a]7.3	77	0.8	12.7	42.2	3.27	2570	1560	81	322	0.112	77.5
□	76-1	42.1	5420	44	[a]7.3	(b)	(b)	(b)	42.1	(b)	2560	1590	63	(b)	(b)	(b)

[a]Closed.
[b]Instrument failure.

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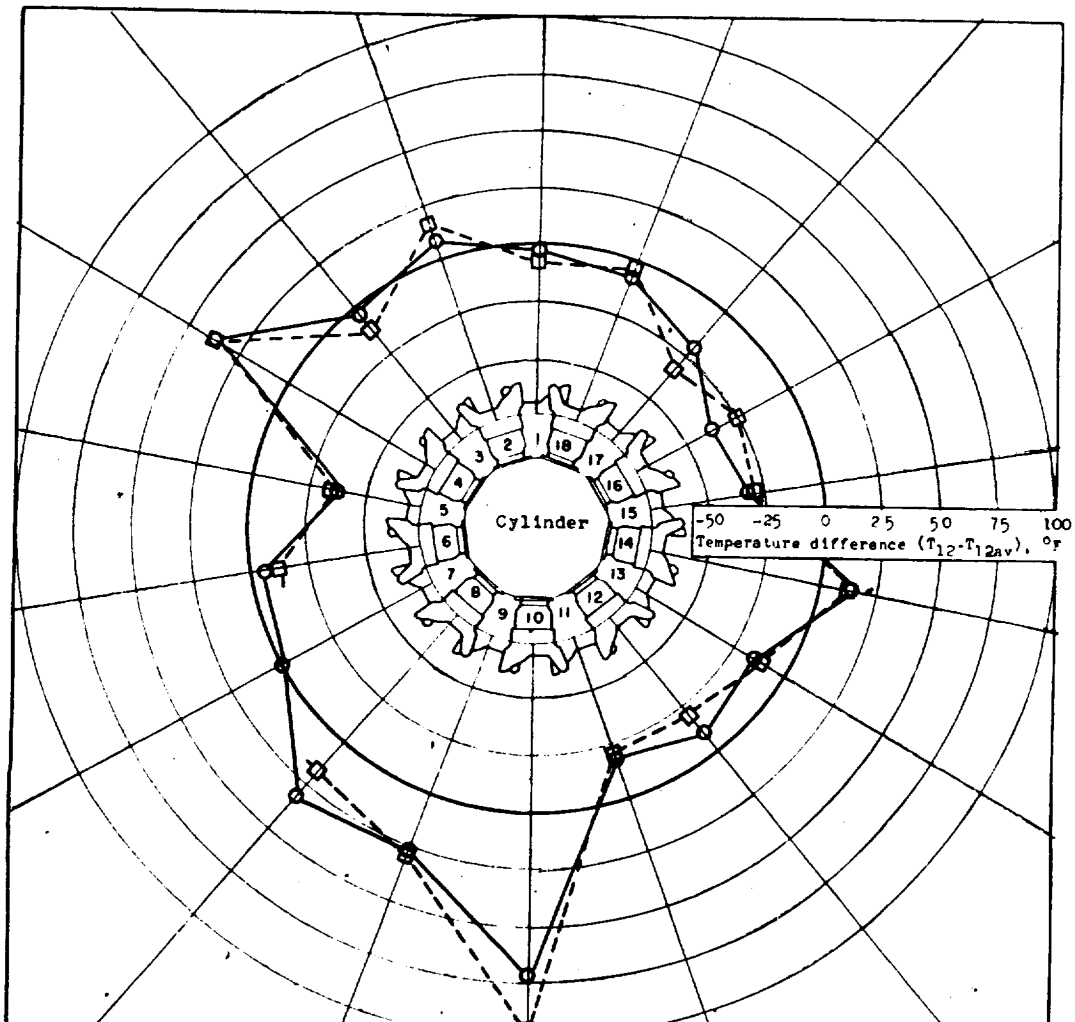

Figure 8. - Comparison of temperature-deviation patterns, $T_{12}-T_{12av}$, for two runs at similar conditions to show reproducibility of temperature data from flight cooling tests of R-2800-21 engine in P-47G airplane. (Specific conditions of two runs given in table.)

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Symbols	Run	Free-stream impact pressure (in. water)	Density altitude (ft)	Free-air temperature (°F)	Cowl-flap opening (deg)	Intercooler-shutter opening (sq in.)	Inclination of thrust axis (deg)	Cooling-air pressure drop (in. water)	Manifold pressure (in. Hg absolute)	Charge-air flow (lb/sec)	Engine speed (rpm)	Brake horsepower	Carburetor-air temperature (°F)	Average T_{12} engine temperature (°F)	Engine fuel-air ratio	Throttle opening (deg)
○	29-3	33.9	24,440	-47	7.3	86	(a)	5.2	42.2	3.54	2580	1590	35	316	0.112	78
□	39-4	38.1	23,810	-45	7.3	68	2.0	6.1	50.1	3.38	2730	1930	66	355	(a)	78
◇	16-1	24.8	4,880	45	17.6	76	2.7	(a)	28.0	(a)	2590	830	58	286	(a)	27

[a]Instrument failure.

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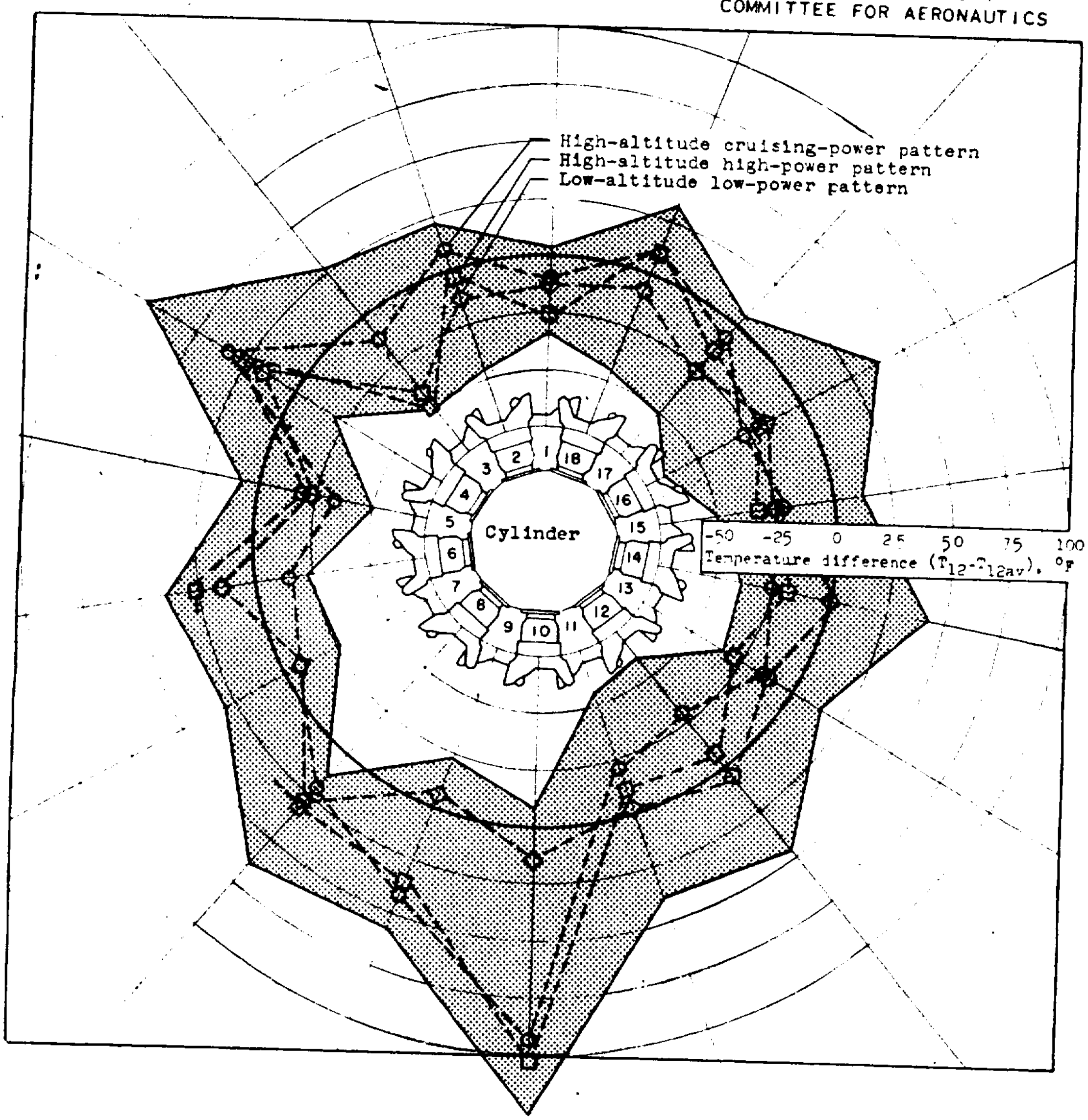

Figure 9. - Temperature-distribution diagram showing range over which individual rear-spark-plug-gasket temperatures T_{12} deviate from average T_{12} value. Data from flight cooling tests of R-2800-21 engine in P-47G airplane.

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Symbols	Run	Free-stream impact pressure (in. water)	Density altitude (ft)	Free-air temperature (°F)	Cowl-flap opening (deg)	Intercooler-shutter opening (sq in.)	Inclination of thrust axis (deg)	Cooling-air pressure drop (in. water)	Manifold pressure (in. Hg absolute)	Charge-air flow (lb/sec)	Engine speed (rpm)	Brake horsepower	Carburetor-air temperature (°F)	Average T_6 engine temperature (°F)	Engine fuel-air ratio	Throttle opening (deg)
○	29-3	33.9	24,440	-47	7.3	86	(a)	5.2	42.2	3.54	2580	1590	35	270	0.112	78
□	39-4	38.1	23,810	-45	7.3	68	2.0	6.1	50.1	3.38	2730	1930	66	292	(a)	78
◇	16-1	24.8	4,880	45	17.6	76	2.70	(a)	28.0	(a)	2590	830	56	218	(a)	27

[a]Instrument failure.

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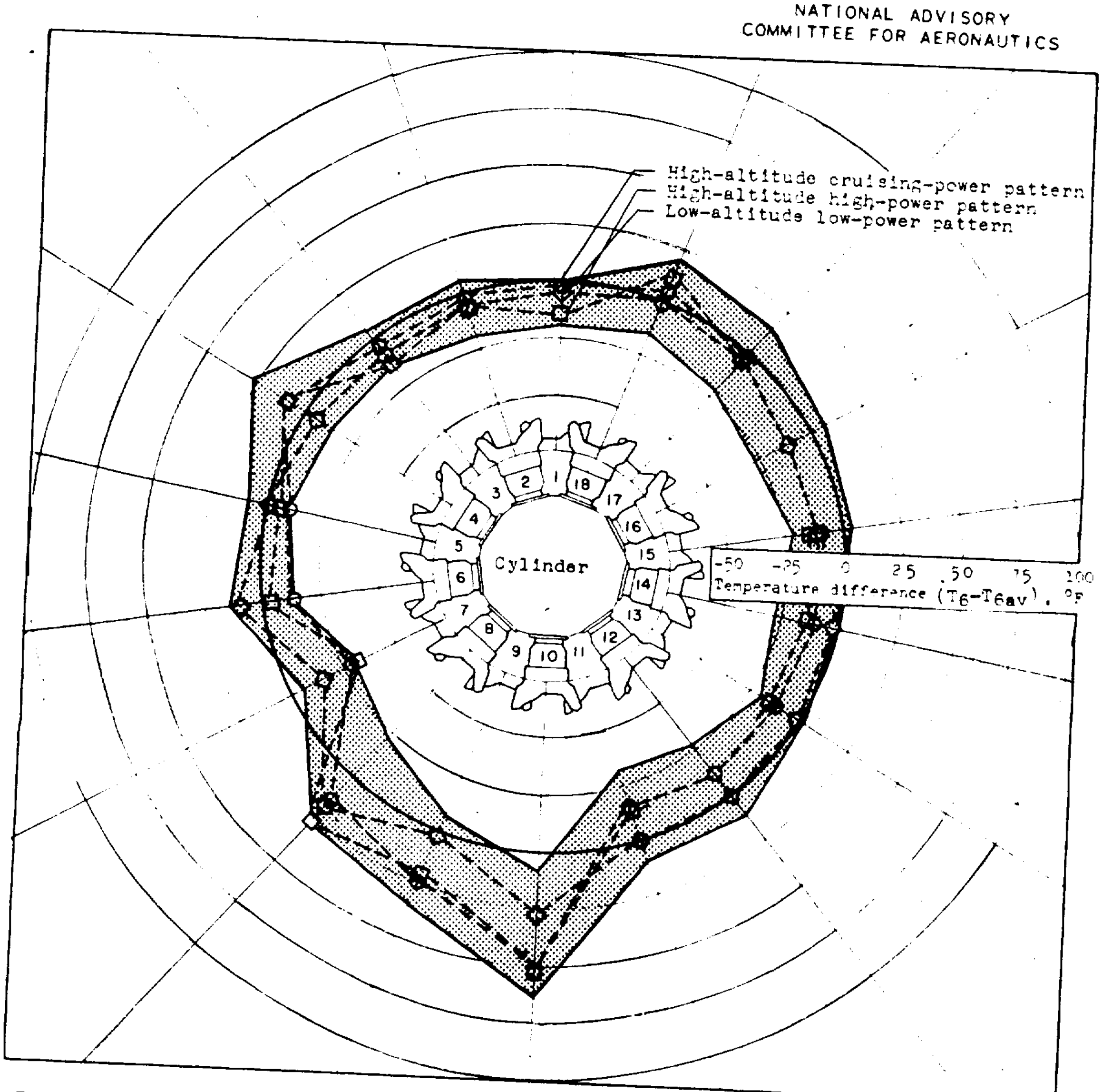

Figure 10. - Temperature-distribution diagram showing range over which individual middle-rear-cylinder-barrel temperatures T_6 deviate from average T_6 value. Data from flight cooling tests of R-2800-21 engine in P-47G airplane.

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Symbols	Run	Free-stream impact pressure (in. water)	Density altitude (ft)	Free-air temperature (°F)	Cowl-flap opening (deg)	Intercooler-shutter opening (sq in.)	Inclination of thrust axis (deg)	Cooling-air pressure drop (in. water)	Manifold pressure (in. Hg absolute)	Charge-air flow (lb/sec)	Engine speed (rpm)	Brake horsepower	Carburetor-air temperature (°F)	Average T_{12} engine temperature (°F)	Engine fuel-air ratio	Throttle opening (deg)
○	24-2	29.1	3,440	13	11.7	70	1.9	13.0	29.0	2.28	2580	1030	34	263	0.097	28
□	20-2	20.5	26,200	-17	11.6	19	3.7	4.6	27.0	2.22	2600	1010	26	285	.107	78

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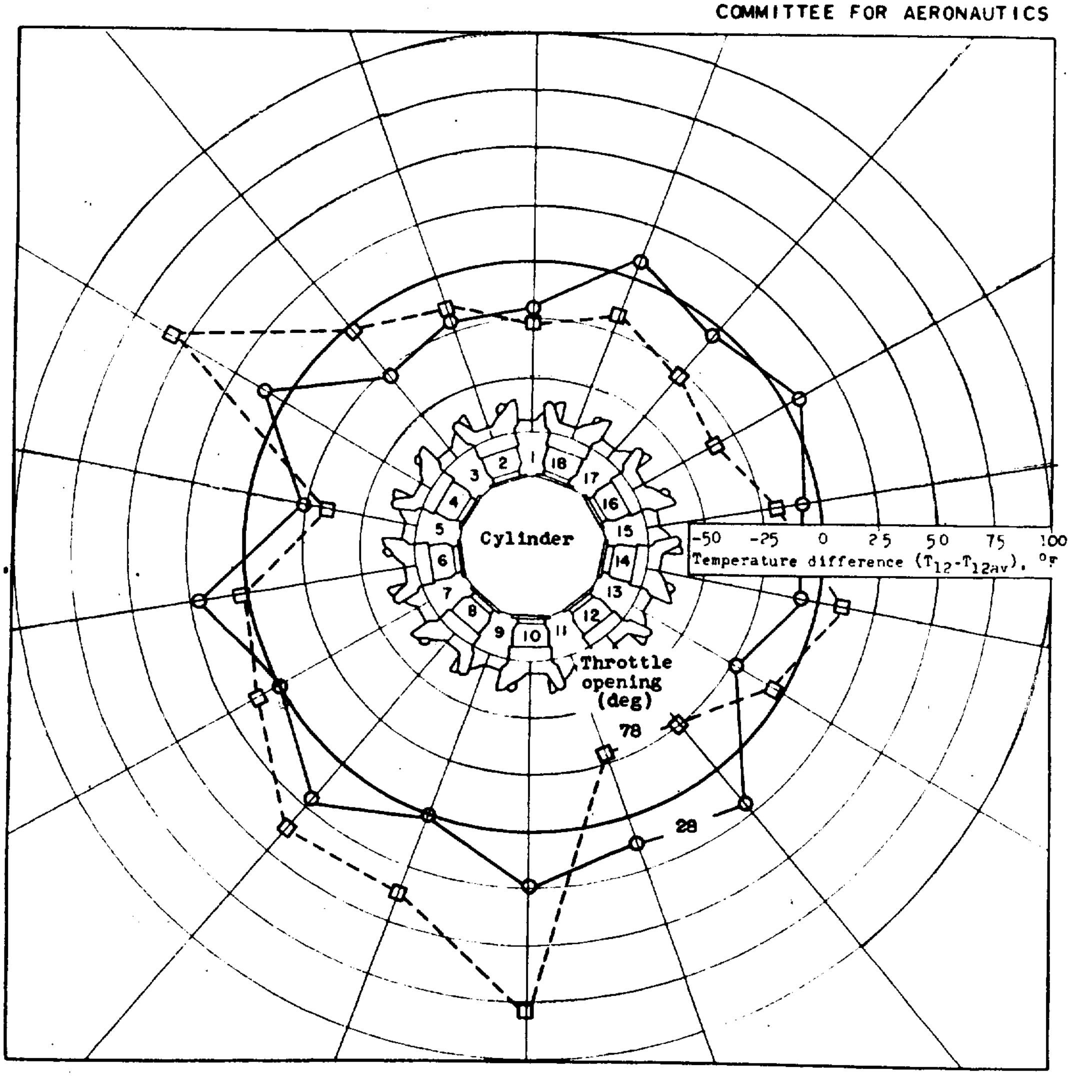

Figure 11. - Temperature-deviation patterns showing effect of changing throttle position. Charge-air flow, constant. Data taken from flight cooling tests of R-2800-21 engine in P-47G airplane.

152-744

Limit	Free-stream impact pressure (in. water)	Density altitude (ft)	Free-air temperature (°F)	Cowl-flap opening (deg)	Intercooler-shutter opening (sq in.)	Inclination of thrust axis (deg)	Cooling-air pressure drop (in. water)	Manifold pressure (in. Hg absolute)	Charge-air flow (lb/sec)	Engine speed (rpm)	Brake horsepower	Carburetor-air temperature (°F)	Average T_{12} engine temperature (°F)	Engine fuel-air ratio	Throttle opening (deg)
Lower	20.2	3,000	15	11.8	(a)	1.8	10.2	34.1	2.73	2570	1240	24	246	0.107	35
Upper	37.8	10,630	43	14.2	172	3.0	16.9	40.3	(b)	2590	1470	62	300	(b)	48

[a]Closed.
[b]Instrument failure.

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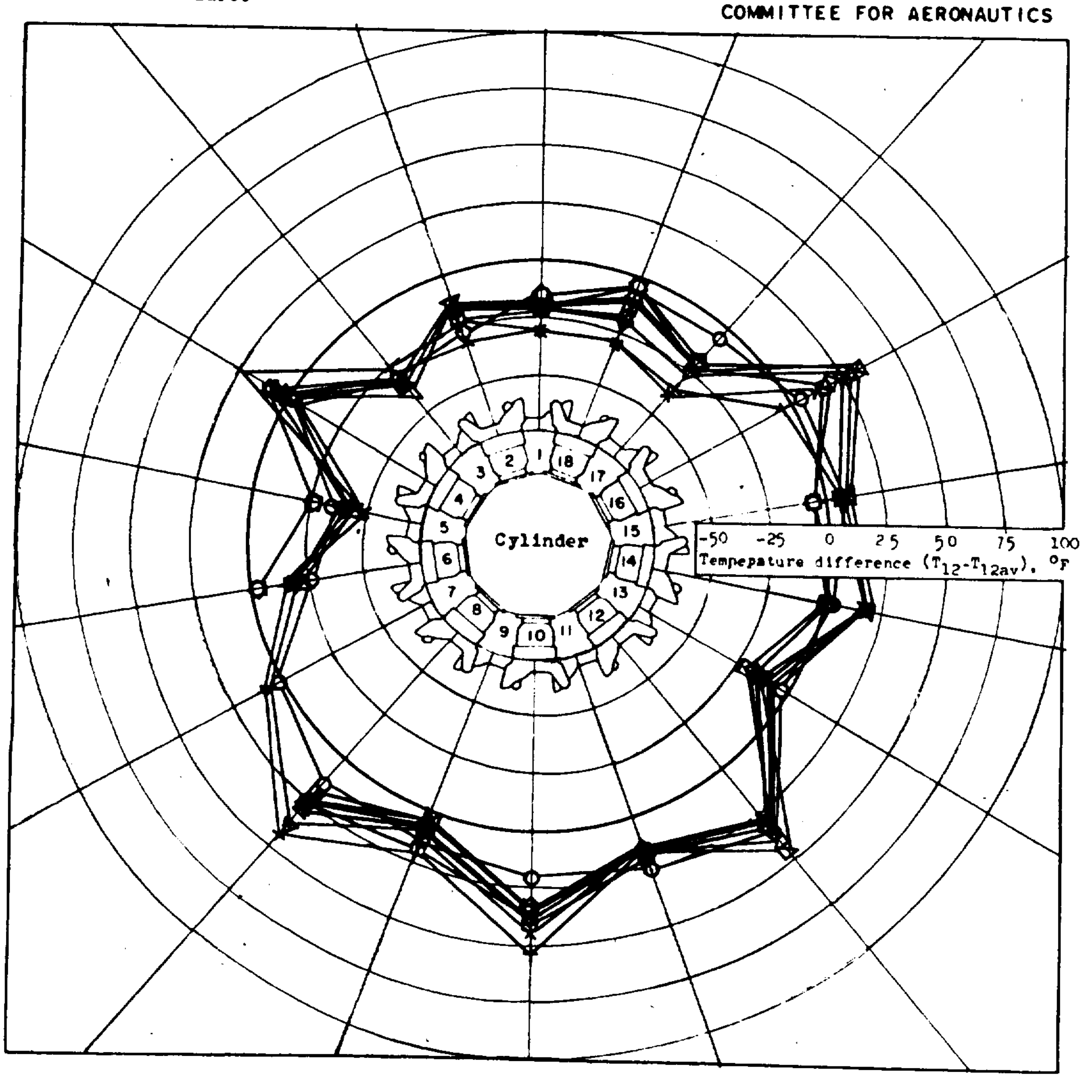

Figure 12. - Temperature-deviation patterns of several runs at varying conditions except all runs were made with throttle from 35° to 48° open. Data taken from flight cooling tests of R-2800-21 engine in P-47C airplane.

Limit	Free-stream impact pressure (in. water)	Density altitude (ft)	Free-air temperature (°F)	Cowl-flap opening (deg)	Intercooler-shutter opening (sq in.)	Inclination of thrust axis (deg)	Cooling-air pressure drop (in. water)	Manifold pressure (in. Hg absolute)	Charge-air flow (lb/sec)	Engine speed (rpm)	Brake horsepower	Carburetor-air temperature (°F)	Average T_{12} engine temperature (°F)	Engine fuel-air ratio	Throttle opening (deg)
Lower	14.2	4,260	-70	10.2	2	1.3	3.9	35.1	2.23	1920	1130	15	263	0.088	78
Upper	37.2	27,980	43	15.2	82	5.8	19.7	42.4	3.51	2580	1570	72	313	.115	78

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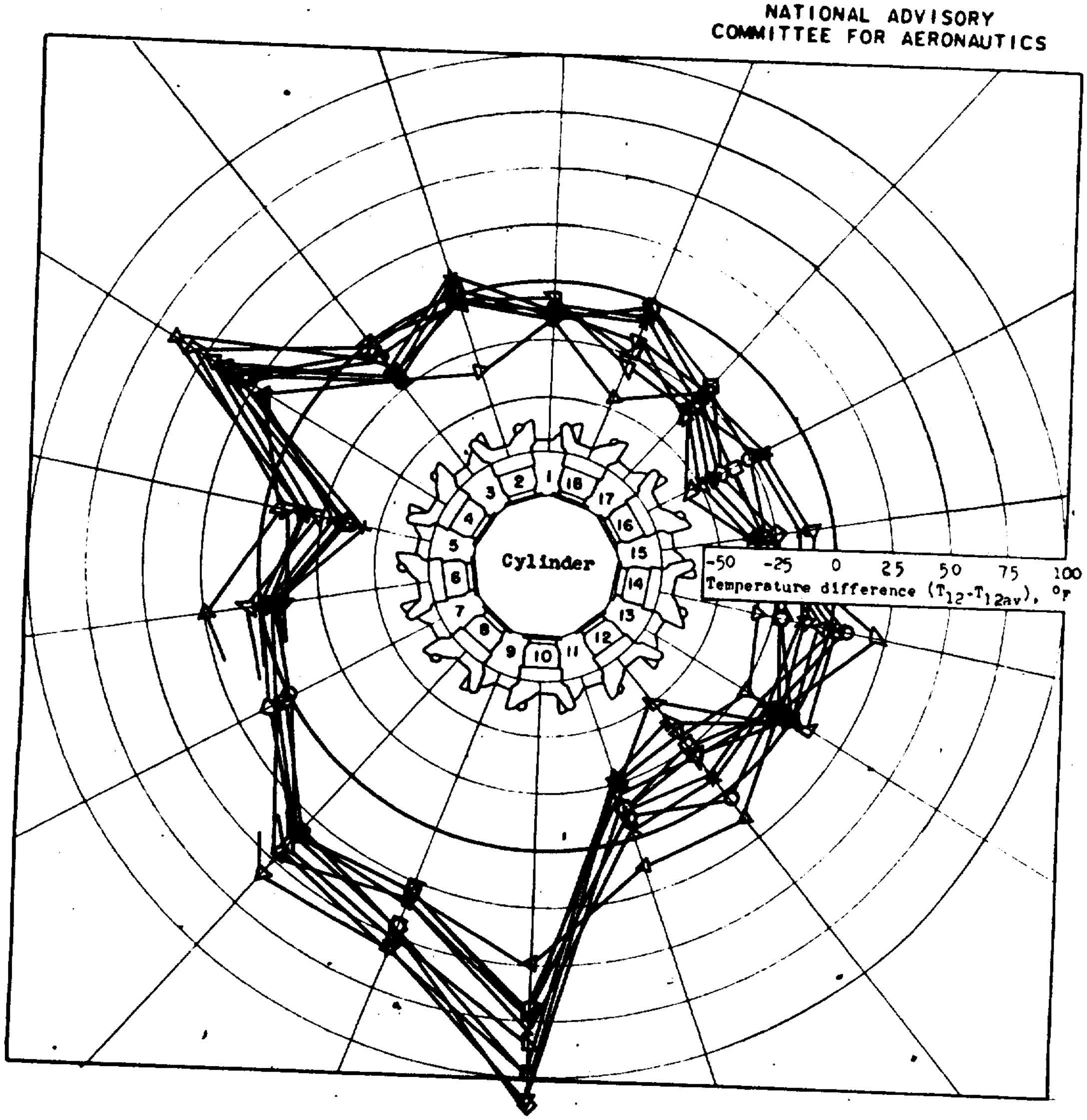

Figure 13. - Temperature-deviation patterns of several flight runs at varying conditions except all runs were made with throttle in wide-open position. Data taken from flight cooling tests of R-2800-21 engine in P-47G airplane.

152-744

Symbols	Run	Free-stream impact pressure (in. water)	Density altitude (ft)	Free-air temperature (°F)	Cowl-flap opening (deg)	Intercooler-shutter opening (sq in.)	Inclination of thrust axis (deg)	Cooling-air pressure drop (in. water)	Manifold pressure (in. Hg absolute)	Charge-air flow (lb/sec)	Engine speed (rpm)	Brake horsepower	Carburetor-air temperature (°F)	Average T_{12} engine temperature (°F)	Engine fuel-air ratio	Throttle opening (deg)
○	22-1	23.4	3990	24	12.0	74	3.0	10.1	32.6	1.54	1600	800	42	253	0.074	46
□	23-4	20.5	5460	43	14.2	72	2.9	10.2	38.1	3.00	2570	1410	62	300	.112	48

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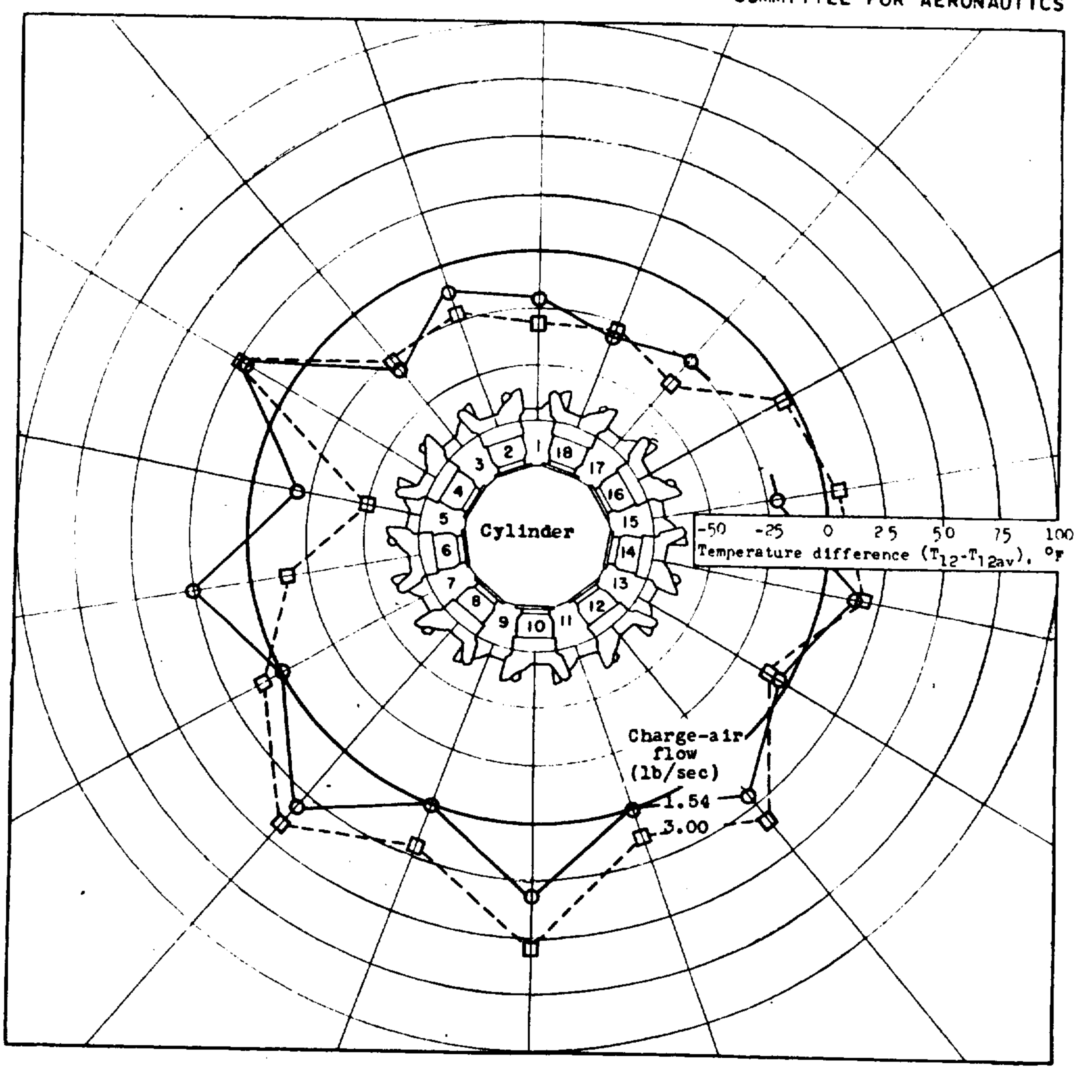

Figure 14. - Temperature-deviation patterns showing effect of varying charge-air flow with throttle fixed at approximately two-thirds open. Data taken from flight cooling tests of R-2800-21 engine in P-47G airplane.

152-744

Symbols	Run	Free-stream impact pressure (in. water)	Density altitude (ft)	Free-air temperature (°F)	Cowl-flap opening (deg)	Intercooler-shutter opening (sq in.)	Inclination of thrust axis (deg)	Cooling-air pressure drop (in. water)	Manifold pressure (in. Hg absolute)	Charge-air flow (lb/sec)	Engine speed (rpm)	Brake horsepower	Carburetor-air temperature (°F)	Average T_{12} engine temperature (°F)	Engine fuel-air ratio	Throttle opening (deg)
○	41-3	27.3	9480	5	11.7	70	2.8	11.0	29.7	2.08	2200	1020	31	263	0.093	38
□	41-4	27.0	9470	5	11.7	70	2.7	11.1	27.9	2.10	2410	1000	31	267	.094	34
◇	41-6	24.3	9560	5	11.7	70	3.1	9.6	26.0	2.10	2695	930	33	276	.092	32

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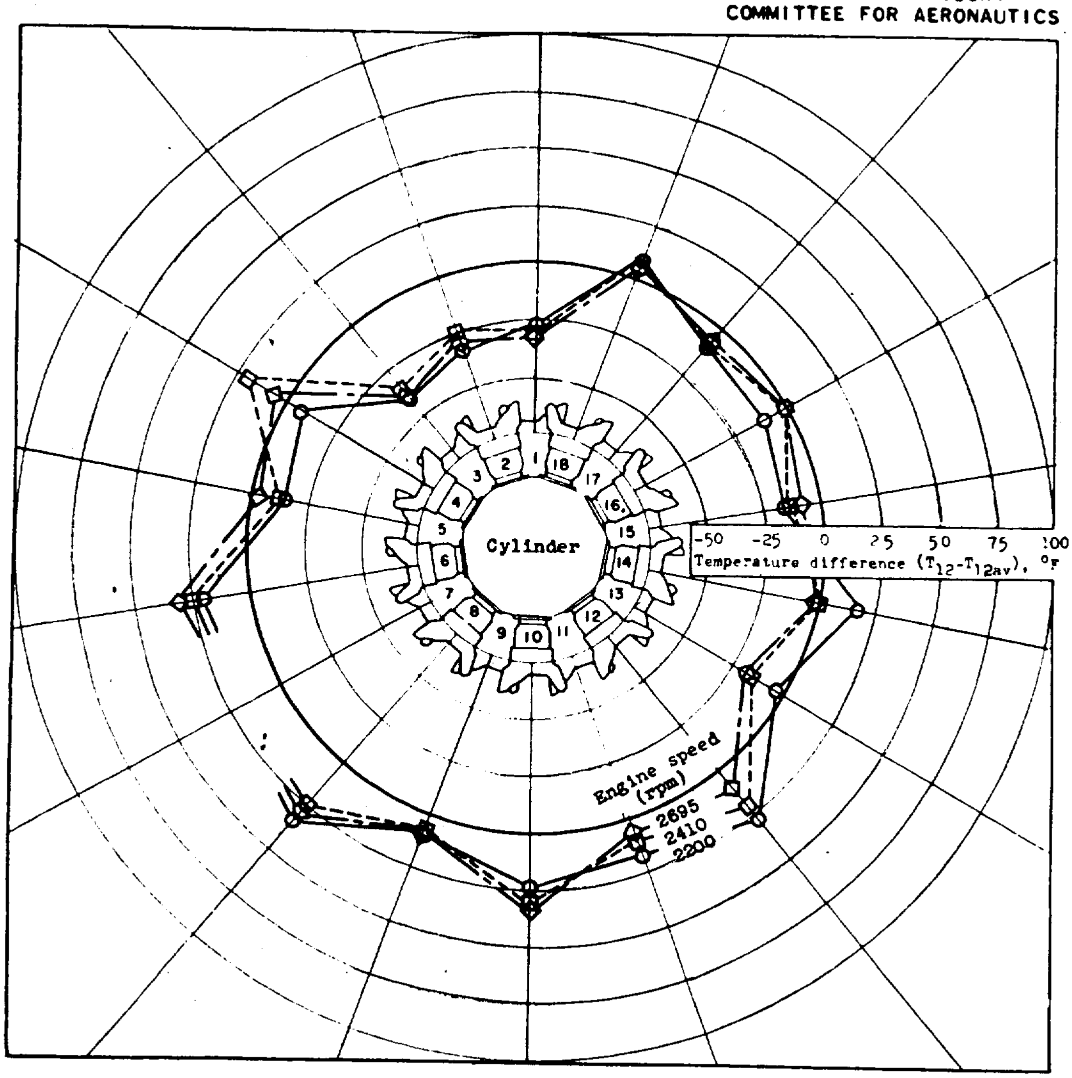

Figure 15. - Temperature-deviation patterns showing effect of varying engine speed. Data taken from flight cooling tests of R-2800-21 engine in P-47G airplane.

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Symbols	Run	Free-stream impact pressure (in. water)	Density altitude (ft)	Free-air temperature (°F)	Cowl-flap opening (deg)	Intercooler-shutter opening (sq in.)	Inclination of thrust axis (deg)	Cooling-air pressure drop (in. water)	Manifold pressure (in. Hg absolute)	Charge-air flow (lb/sec)	Engine speed (rpm)	Brake horsepower	Carburetor-air temperature (°F)	Average T_{12} engine temperature (°F)	Engine fuel-air ratio	Throttle opening (deg)
○	45-3	33.5	4370	27	12.6	(a)	2.1	16.1	34.1	2.75	2570	1250	59	280	0.107	36
□	45-2	31.7	4290	26	12.6	172	2.5	15.0	34.8	2.73	2570	1240	57	287	.107	36

[a]Closed position.

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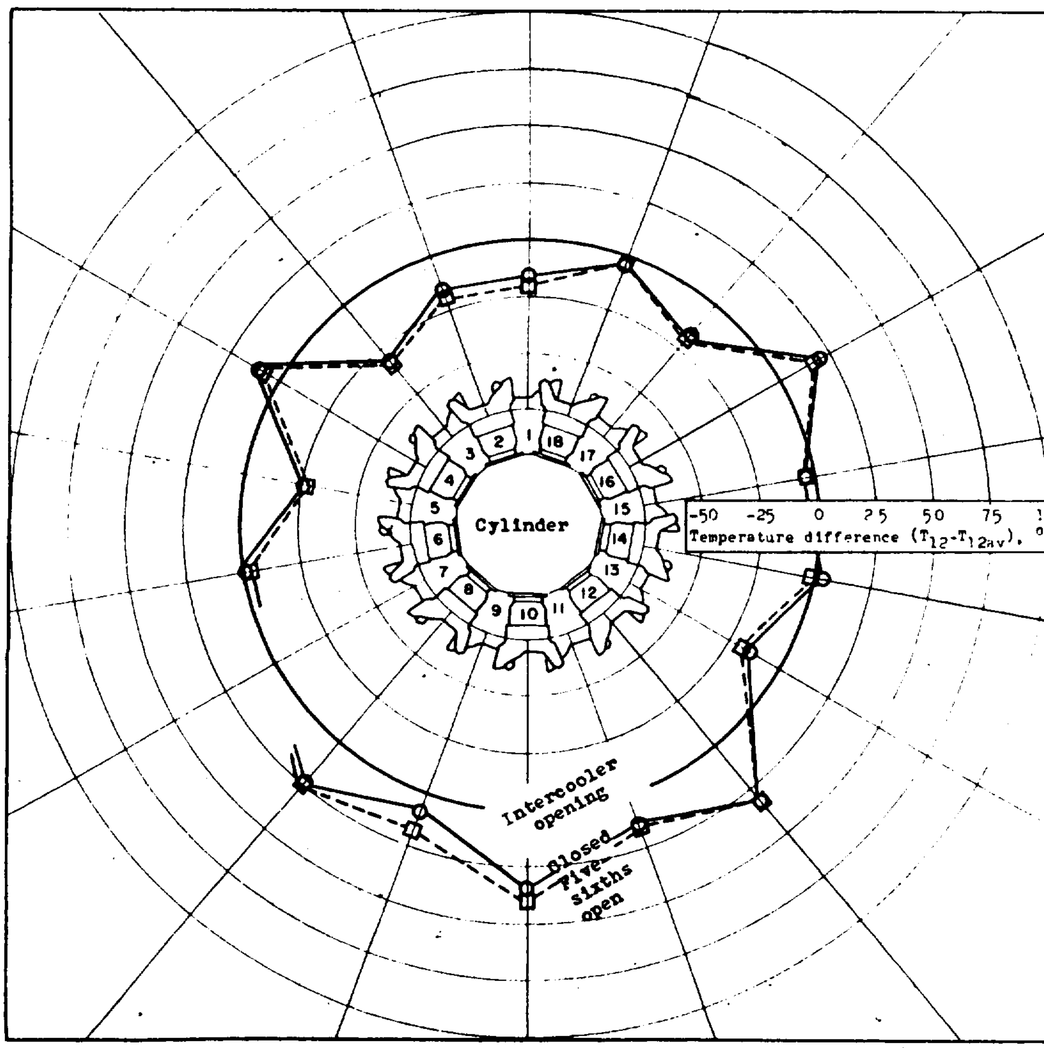

Figure 16. - Temperature-deviation patterns showing effect of varying quantity of auxiliary air. Data taken from flight cooling tests of R-2800-21 engine in P-47G airplane.

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Symbols	Run	Free-stream impact pressure (in. water)	Density altitude (ft)	Free-air temperature (^{o}F)	Cowl-flap opening (deg)	Intercooler-shutter opening (sq in.)	Inclination of thrust axis (deg)	Cooling-air pressure drop (in. water)	Manifold pressure (in. Hg absolute)	Charge-air flow (lb/sec)	Engine speed (rpm)	Brake horsepower	Carburetor-air temperature (^{o}F)	Average T_{12} engine temperature (^{o}F)	Engine fuel-air ratio	Throttle opening (deg)
○	64-4	35.5	5120	43	12.0	69	2.2	16.0	37.9	2.84	2570	1410	78	342	0.080	---[a]
□	64-3	35.6	5210	44	12.1	71	2.5	15.8	37.6	2.84	2570	1380	78	319	.093	---
◇	64-1	34.0	5220	45	12.1	71	2.4	14.7	37.8	2.92	2570	1340	80	304	.102	---

[a]Data not recorded.

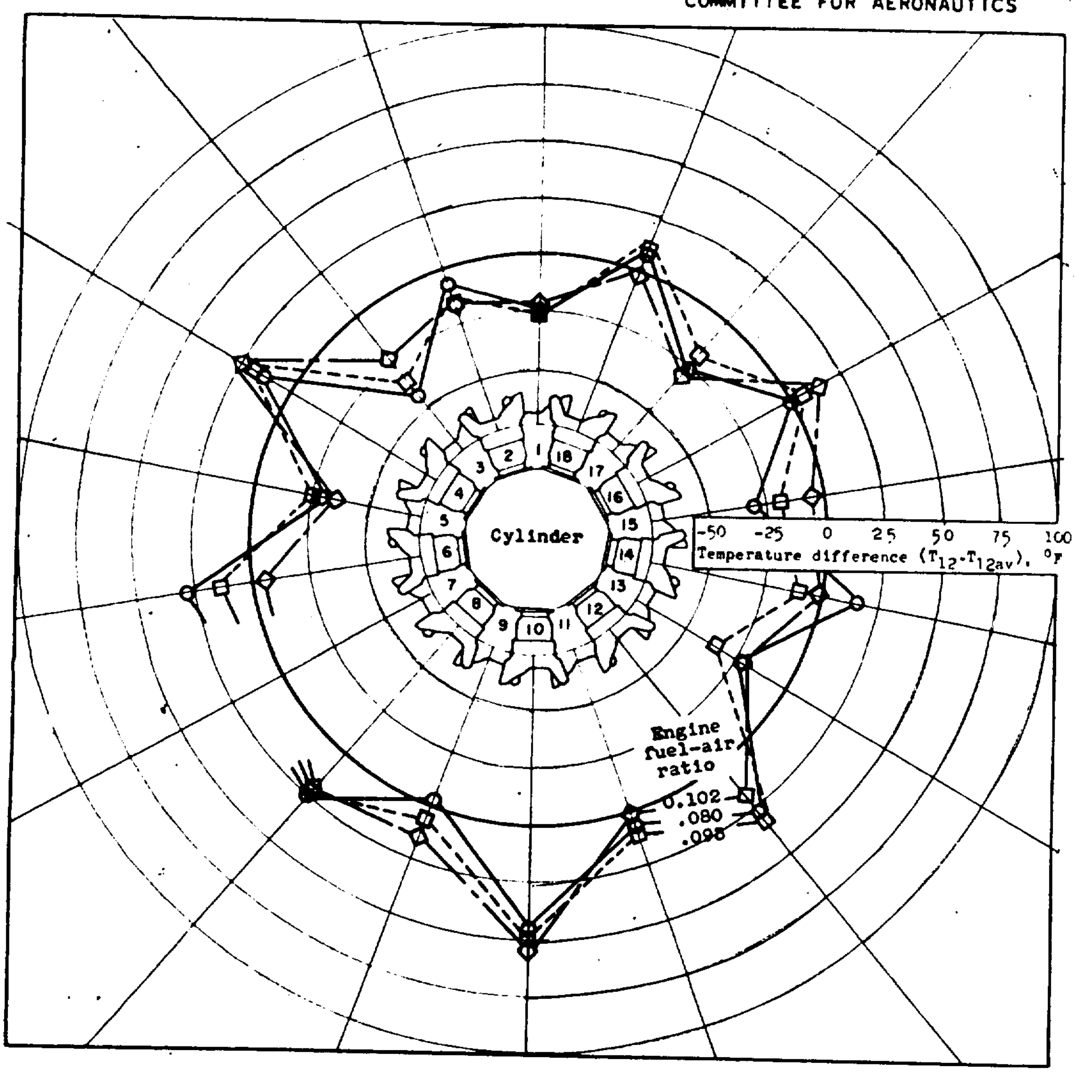

Figure 17. - Temperature-deviation patterns showing effect of varying engine fuel-air ratio. Data taken from flight cooling tests of R-2800-21 engine in P-47D airplane.

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Symbols	Run	Free-stream impact pressure (in. water)	Density altitude (ft)	Free-air temperature (°F)	Cowl-flap opening (deg)	Intercooler-shutter opening (sq in.)	Inclination of thrust axis (deg)	Cooling-air pressure drop (in. water)	Manifold pressure (in. Hg absolute)	Charge-air flow (lb/sec)	Engine speed (rpm)	Brake horsepower	Carburetor-air temperature (°F)	Average T_{12} engine temperature (°F)	Engine fuel-air ratio	Throttle opening (deg)
○	30-3	31.4	28,070	-71	7.3	85	1.5	4.2	1.8	3.56	2550	1270	30	327	0.113	78
□	30-4	15.8	27,870	-68	7.3	82	4.0	2.4	.8	3.37	2540	1280	38	274	.113	78

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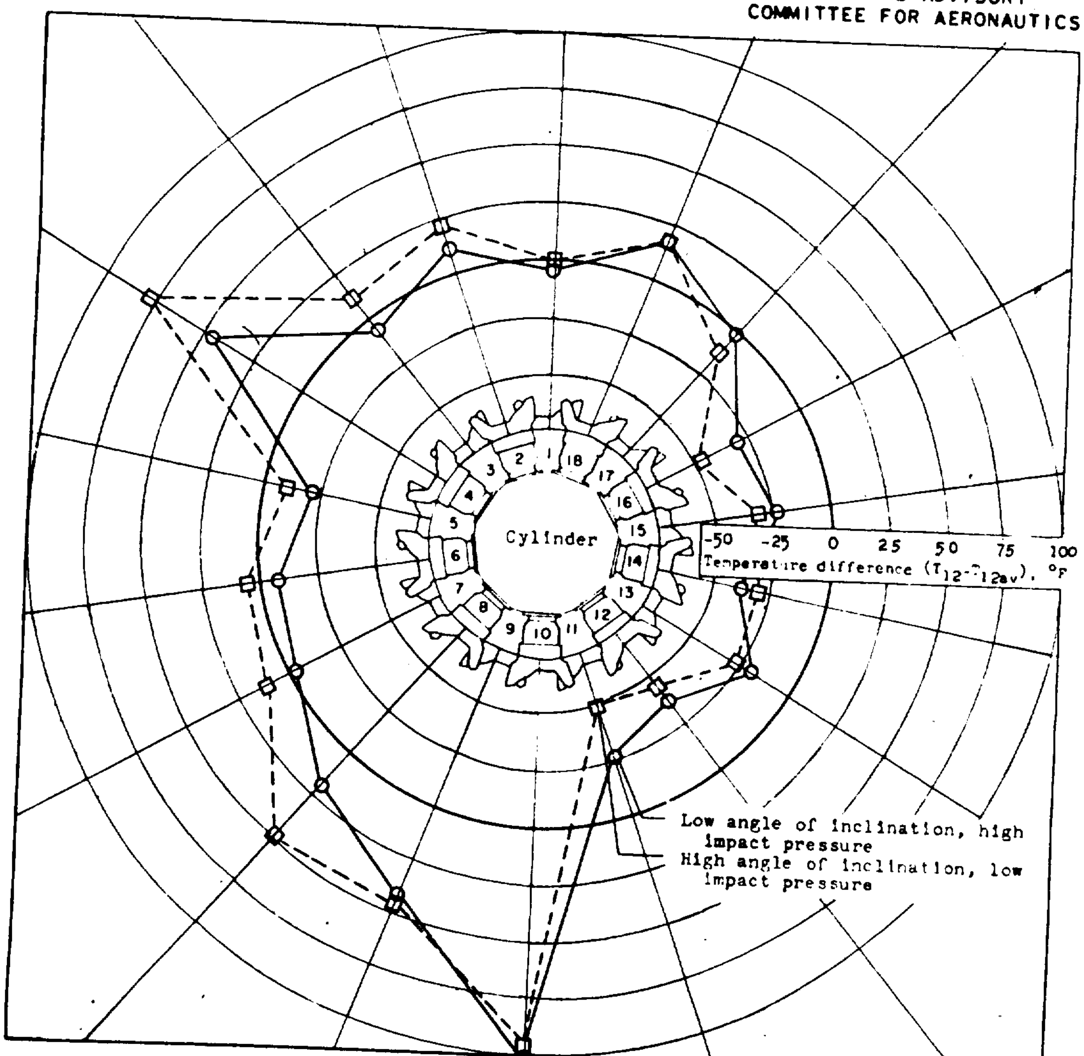

Figure 18. - Temperature-deviation patterns showing effect of changing angle of inclination of thrust axis and impact pressure. Data taken from flight cooling tests of R-2800-21 engine in P-47D airplane.

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Symbols	Run	Free-stream impact pressure (in. water)	Density altitude (ft)	Free-air temperature (°F)	Cowl-flap opening (deg)	Intercooler-shutter opening (sq in.)	Inclination of thrust axis (deg)	Cooling-air pressure drop (in. water)	Manifold pressure (in. Hg absolute)	Charge-air flow (lb/sec)	Engine speed (rpm)	Brake horsepower	Carburetor-air temperature (°F)	Average T_{12} engine temperature (°F)	Engine fuel-air ratio	Throttle opening (deg)
○	24-4	16.8	3440	15	7.2	71	4.3	4.8	28.8	2.20	2580	1010	32	332	0.094	29
□	24-5	16.2	3470	16	11.7	71	4.4	7.5	28.7	2.16	2570	1020	33	297	.096	28
◇	24-6	15.8	3360	14	14.5	71	4.5	9.7	28.9	2.16	2570	1030	30	276	.101	28

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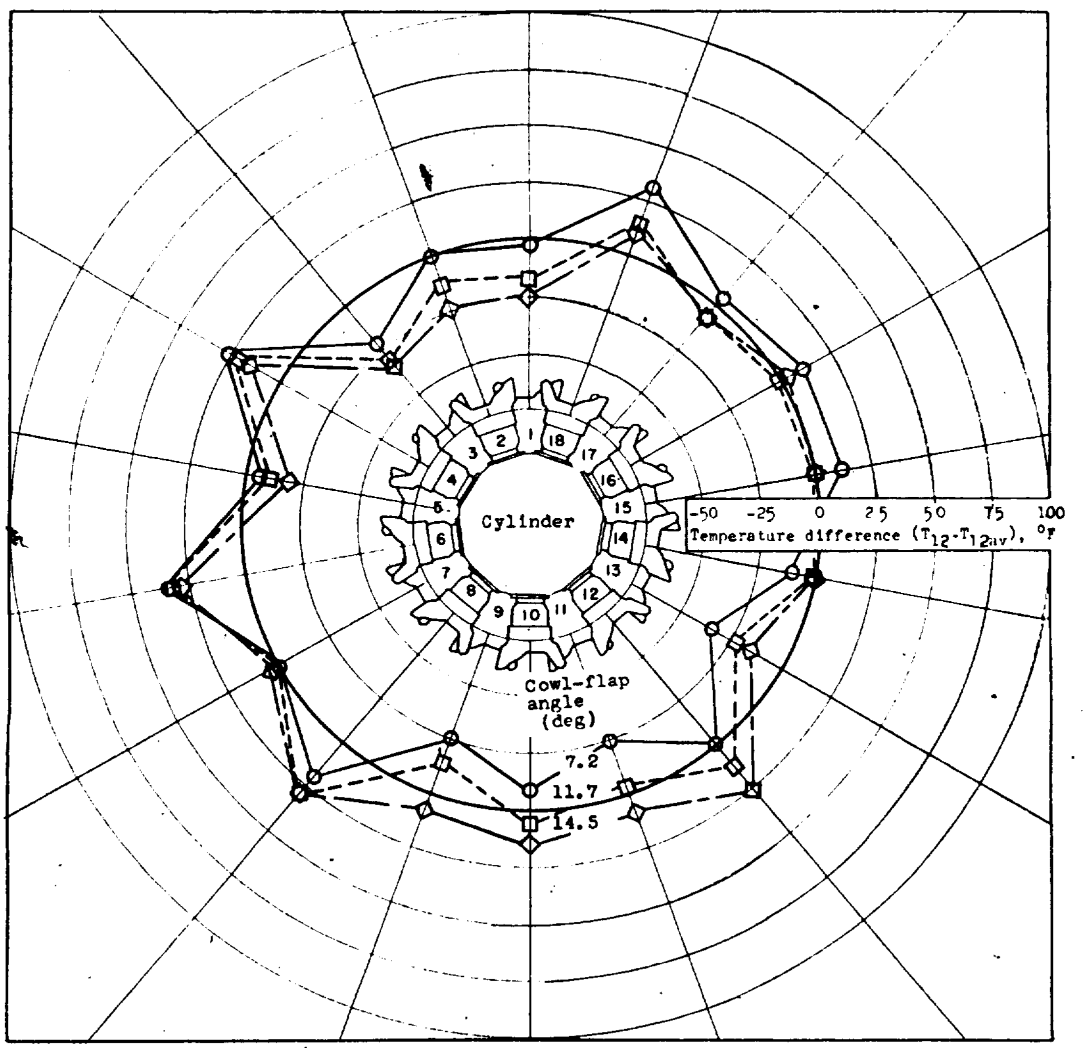

Figure 19. - Temperature-deviation patterns showing effect of varying cowl-flap position. Data taken from flight cooling tests of R-2800-21 engine in P-47G airplane.

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